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NR-238-001  
Contract Nonr-609(02)

Edwards Street Laboratory  
Yale University  
New Haven, Connecticut

ESL Technical Memorandum No. 29  
(ESL 521: Ser 08)  
12 February 1954

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Chief of Naval Research (Code 403)

Apparatus for Survey of a Magnetic Field Pattern  
at the Ocean Surface Established by Equipment Operating  
at 30 Cycles per Second on the Ocean Bottom

G. F. Pieper, and R. W. Jackson

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This report describes equipment designed to be carried on a small boat for the continuous recording over the ocean surface of magnetic field strengths of the order of 0.5 gamma to 50 gamma (5 to 500 microgauss) at 30 c/s. The application of the equipment is described in more detail in (1).

### Requirements

The equipment was designed with the following requirements in mind.

(a) Input: To simplify the winding of pick-up coils a low impedance input into a step-up transformer was decided upon. The input impedance level was somewhat arbitrarily set at 60 ohms.

(b) Output: To drive an Esterline-Angus 0-1 ma. recording milliammeter.

(c) Sensitivity: It was expected that ambient electromagnetic noise would limit measurements much below  $1/3$  gamma. The coils wound to match the 60 ohm input consisted of 215 turns of No. 28 cotenamel copper wire wound on a square form one foot on each side. At 30 c/s the induced Emf in microvolts was 3.75 times the

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magnitude of the magnetic field component in gammas. Consequently a minimum magnitude of magnetic field of  $1/3$  gamma about which measurements were required corresponded to a minimum Emf of 1.25 microvolts.

(d) Internal Noise: Consequent upon (c) amplifier noise from electrical and microphonic origins had to be well below 1 microvolt referred to the input terminals.

(e) Stability: Since the making of the measurements would extend over hours at a time the amplifying and metering circuits had to be as stable as possible. It was hoped that the total effect of component and power supply variations could be kept below 10%.

(f) Time Constant: The minimum speed at which a boat could maintain a stable course in spite of wind and tidal currents was 3 to 4 knots, that is, 5.0 to 6.6 feet/sec. The minimum depth of water was about 30 feet. The most rapid variations in field strength might be expected to take place in distances of the order of half the water depth. Thus the time constant of the circuits should be short compared to the time required to traverse 15 feet, or short compared to 2

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seconds, say.

(g) Selectivity: The narrower the bandwidth the better the noise figure, but the selectivity could not be so high as to lengthen the time constant, nor so high that drifts in component values or variations in exciting frequency would appreciably affect the response by putting the amplifier off tune.

(h) Amplitude Range: A wide range of field strengths (0.5 to 50 gamma) was expected as the boat traversed the survey area, and it was expected that the range would be covered too quickly to allow switching of scales without losing valuable segments of the records. Hence a logarithmic meter response was required.

(i) Portability: The equipment was required to have low enough current drain to be powered from storage batteries for hours at a time, and had to be of reasonable weight and size to allow carrying on and off small boats for regular checking and calibration.

### Design

Beginning at the output end (refer to the circuit



diagram, Fig. 1) the output circuit was designed to have an output resistance of about 50,000 ohms for critical damping of the Esterline-Angus meter, under which condition the time constant of the meter was 0.5 sec.

The remainder of the output circuit was determined by the requirements of the Kay-Lab Type 511C logarithmic attenuator used to obtain a logarithmic response. The output of this device ranges from 0.055 volt to 0.34 volt peak for its maximum working input range of 0.20 volt to 40 volt peak. The output voltage is instantaneously proportional to the logarithm of the input voltage, and thus in the upper part of its working range the output for a sine wave input is a highly compressed waveform approaching a square wave in shape. Since the peak value of this waveform is strictly proportional to the logarithm of the input the device must be followed by a peak reading rectifier. To respond only to the peak value of such a flat topped waveform means, in terms of the simple back-biasing diode circuit, that the rectifier must conduct only for a very short time during the peak portion of the cycle and therefore that (1) the time constant of the diode load must be extremely long compared to the fundamental

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period of the waveform, (2) the impedance of the driving circuit must be low to allow a high rate of transfer of charge during the diode conduction period, (3) the amplitude of driving voltage must be high, especially where crystal diodes are used, to allow accurate voltage discrimination by the diodes in spite of the finite extent of the bend in their transfer characteristics, (4) the frequency response of the driving amplifier must be sufficiently flat that the logarithmic wave shape is preserved with negligible distortion.

The above requirements were reasonably well met by the circuit used, although there was some error at high input, owing to the increase of output impedance of the rectifier driving circuit for negative-going peaks. This error (of the order of 10%) was tolerated for the sake of low current requirements so that the current needs of the entire amplifier and metering circuit would be within the regulating range of a gas-discharge voltage regulator tube. For a peak input of 0.34 volt from the logarithmic attenuator the voltage applied to the rectifier was about 24 volts peak, at an impedance of about 30 ohms. The required long rectifier

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time constant had to be a compromise with requirement (f) above, and was made 1 sec. A phase-synchronized pulsed detector circuit has been developed to give a faster response, but was not ready in time to be used for the summer's measurements.

The driving amplifier for the logarithmic attenuator consists of  $V_7$ ,  $V_8$ ,  $V_9$ , giving a maximum output of 40 volts peak at about 15 ohms output impedance. The gain is 20 and the feedback stabilization factor is 50.

$V_6$  is a voltage amplifier stage built around the Engineering Research Associates plug-in amplifier unit type 416C2. This unit gives a single-stage gain of about 8000. The gain is stabilized by feedback at 500, giving a stabilization factor of about 16 in addition to the inherent stability of the unit against power supply fluctuations.

$V_5$  is a cathode follower stage to match the high impedance of the 60 c/s rejection filter and the attenuator to the low impedance input of the following stage ( $V_6$ ). The stage comprising  $V_3$  and  $V_4$  has a gain of 16. Feedback stabilizes the gain by a factor of 10

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and at the same time reduces the output impedance to match the 60 c/s rejection filter. The 60 c/s rejection filter was included since the 60 c/s power frequency fields were expected to be the most troublesome source of interference. The filter was incorporated as early in the circuit as its impedance requirements could be met in order to keep intermodulation of the 60 c/s with the desired signal to a minimum.

In the input stage  $V_1$  and  $V_2$ , a compromise had to be made between selectivity and stability. A cascode circuit was used for the maximum gain in a single stage in order to simplify the feedback problem and at the same time allow the use of the low-noise triode type 12AY7. The gain of the cascode circuit as shown was about 100 without feedback. Choosing a factor 10 as the minimum gain stabilization acceptable left a gain sufficient for only a limited degree of selectivity ("Q" about 1.5 to 2.5)<sup>2</sup>. The stabilizing negative feedback is applied through the unbalance in the parallel-T network. The use of a single feedback loop over the whole preamplifier ( $V_1$  and  $V_4$ ), possibly including the input transformer, would have been

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preferable to the two separate feedback loops for stabilizing the overall gain and reducing intermodulation but time did not allow working out the more critical details of the longer feedback path. The preamplifier stages (shown inside the broken line) are on a sub-chassis fixed to the main chassis by soft rubber shock mounts.

The overall frequency response from the primary of the input transformer to the input to the logarithmic attenuator is shown in Fig. 2. The voltage gain at 30 c/s is about  $6 \times 10^6$  or 135 db, giving maximum (full scale) output for an input of about 5 microvolts. The noise level for a 60 ohm resistive termination at the input was measured at  $1.2 \times 10^{-8}$  volts. A lower noise level probably could have been obtained by selection and aging of input tubes. In practice the noise level was determined by motion of the pickup coil in the earth's magnetic field and was usually about 1/2 microvolt.

Two complete amplifiers were built so that two components of the magnetic field could be measured at one time. The high voltage requirements for both amplifiers were met by a single vibrator power supply (Fig. 3) drawing about 5 amperes from a 6 volt storage

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battery. Total filament current was 5.7 amperes and was supplied from a second storage battery. The amplifier components and wiring were sprayed with "Krylon" plastic spray to guard against corrosion and condensation from the moist atmosphere.

The Equipment including the two clock-work driven Esterline-Angus recording meters is shown as mounted in a boat in Fig. 4. The meters were insulated from shocks and engine vibrations by soft foam rubber.

*G. F. Pieper*  
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*R. W. Jackson*  
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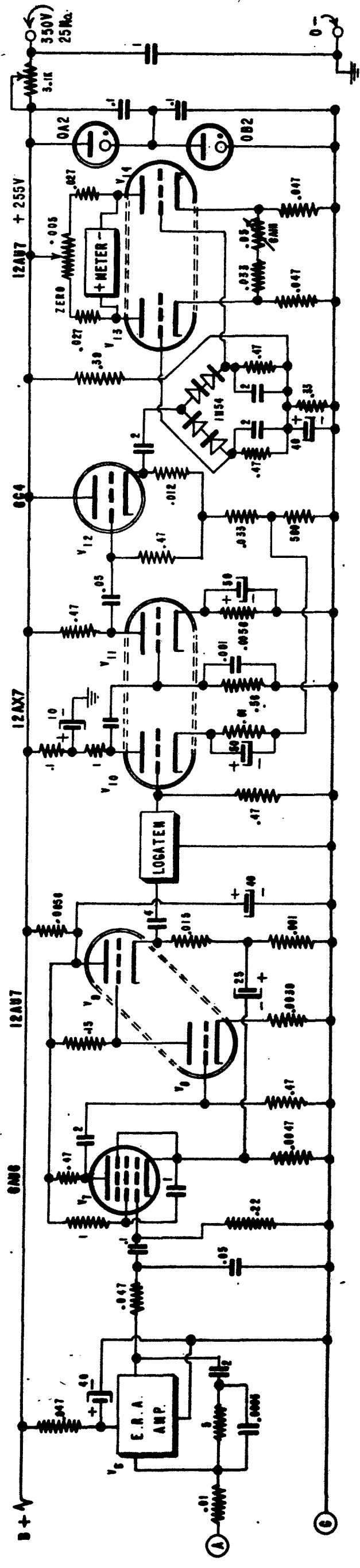
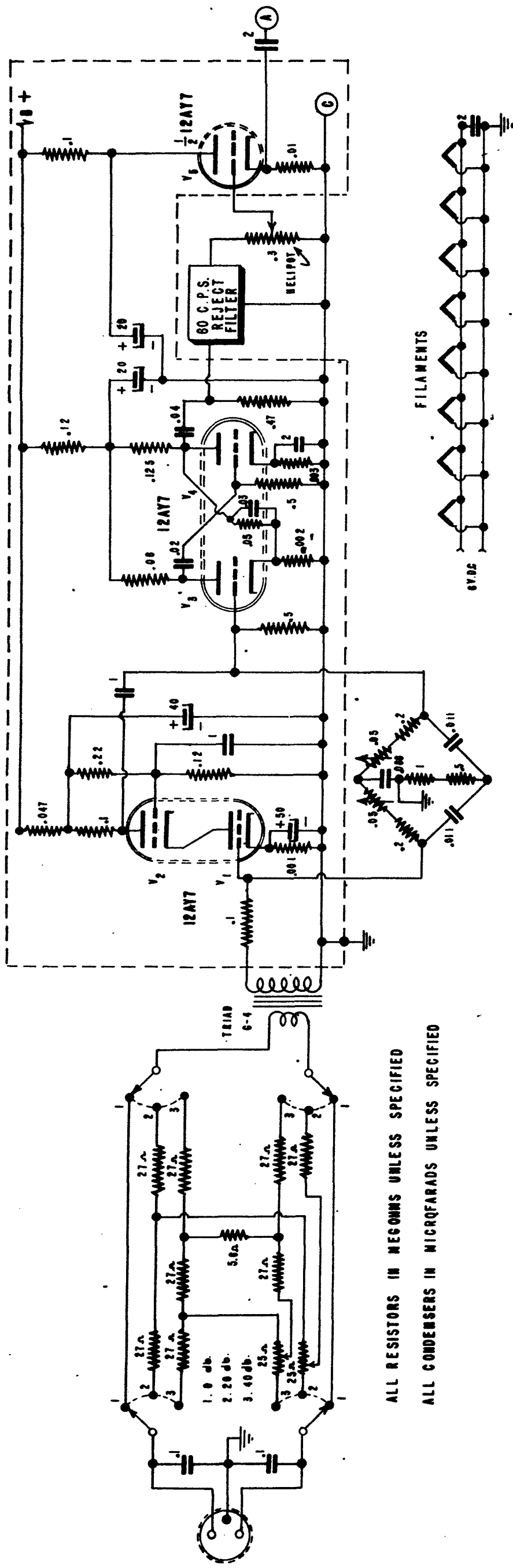
References

1. Pieper, G. F., Whorf, R. P., Davis, A. A., Jackson, R. W., "Survey of the Magnetic Field at the Surface Due to an Underwater Electrode System." Technical Report No. 28, Edwards Street Laboratory, Yale University, New Haven, Connecticut, 12 February 1954.

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2. For details see: Valley and Wallman. "Vacuum Tube Amplifiers." p. 393.

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60 CPS REJECTION FILTER: KAY-LAB TWIN-T' FILTER, MODEL 503A0 - KALBFELL LABORATORIES, INC., 1090 MERENA BLVD, SAN DIEGO 10, CAL.

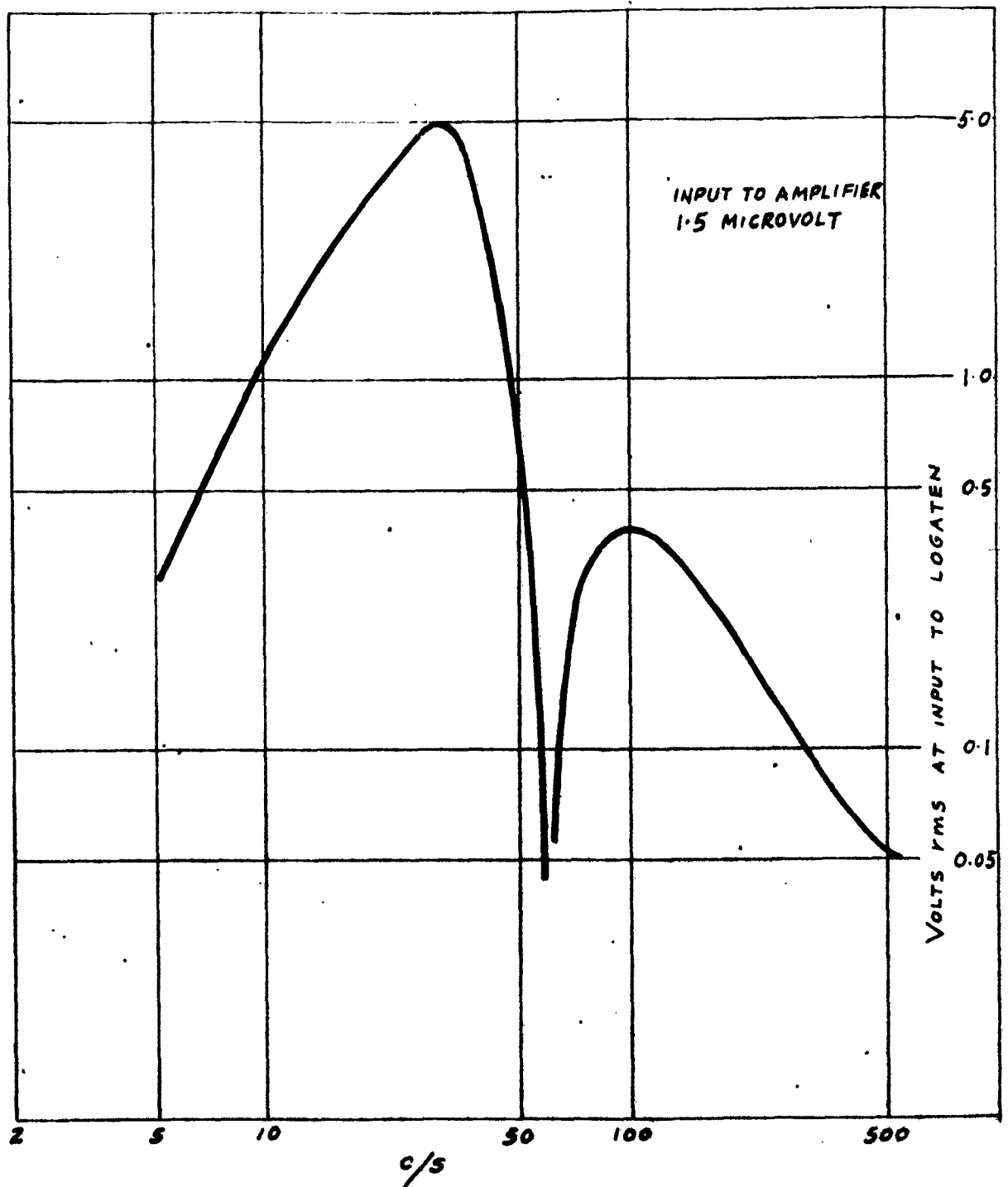
ERA AMP: PLUG-IN-AMPLIFIER TYPE 418C2, ENGINEERING RESEARCH ASSOC. INC., 1902 W. MINNEAPOLIS AVE., ST. PAUL 4, MINN.

LOCATEN: KAY-LAB LOGARITHMIC ATTENUATOR MODEL 511C - KALBFELL LABORATORIES, INC., 1090 MERENA BLVD. SAN DIEGO 10, CAL.

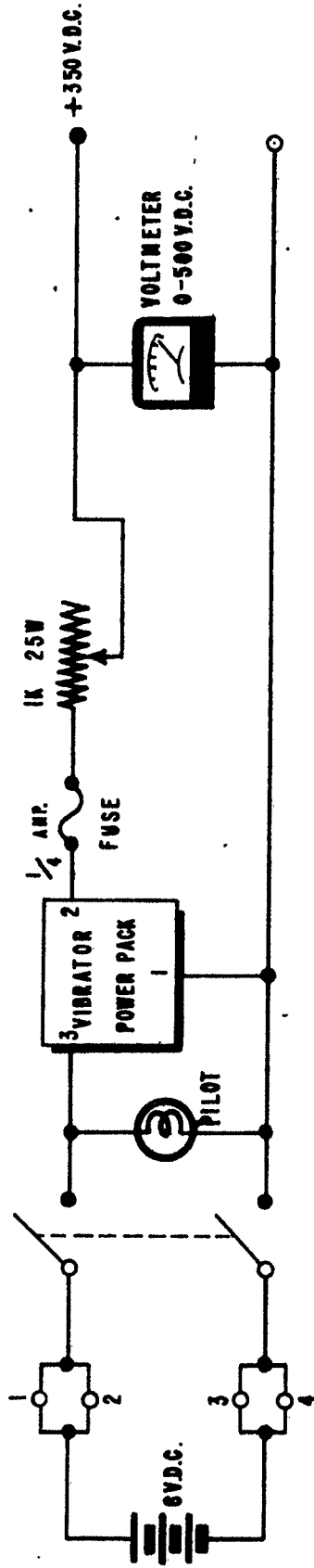
METER: ESTERLINE ARGUS D.C. MILLIAMETER FULL SCALE 1MA. - E.A. CO. INC., P.O. BOX 596 INDIANAPOLIS 8, IND.

FIG. 1 AMPLIFIER CIRCUIT DIAGRAM



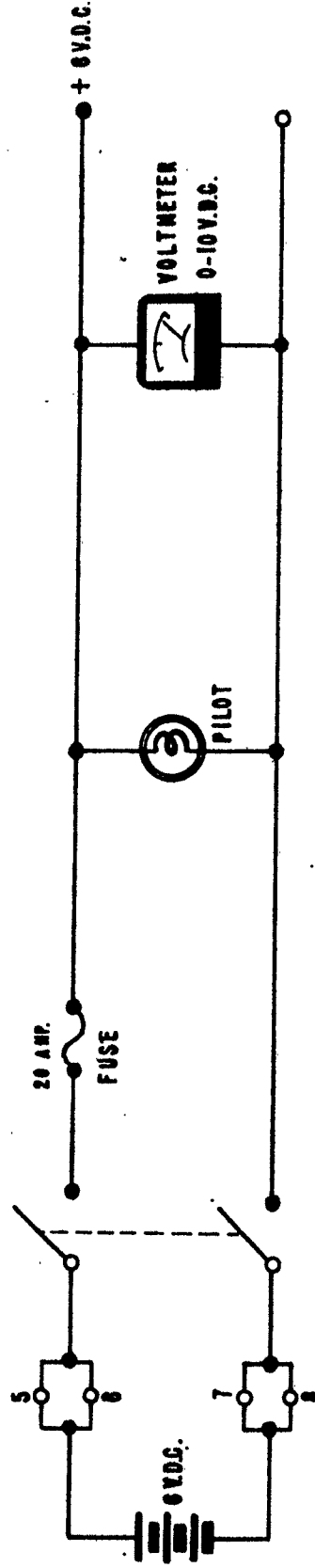


**FIG. 2.** AMPLIFIER FREQUENCY RESPONSE



6VOLTS D.C. SUPPLIED FROM AUTOMOBILE STORAGE BATTERY  
 VIBRATOR POWER PACK: RADIART 'VIPOWER' MODEL NO. 453

MANUFACTURED BY RADIART CORP. CLEVELAND 2, OHIO



6 VOLTS D.C. SUPPLIED FROM AUTOMOBILE STORAGE BATTERY

FIG.3 POWER SUPPLY WIRING DIAGRAM

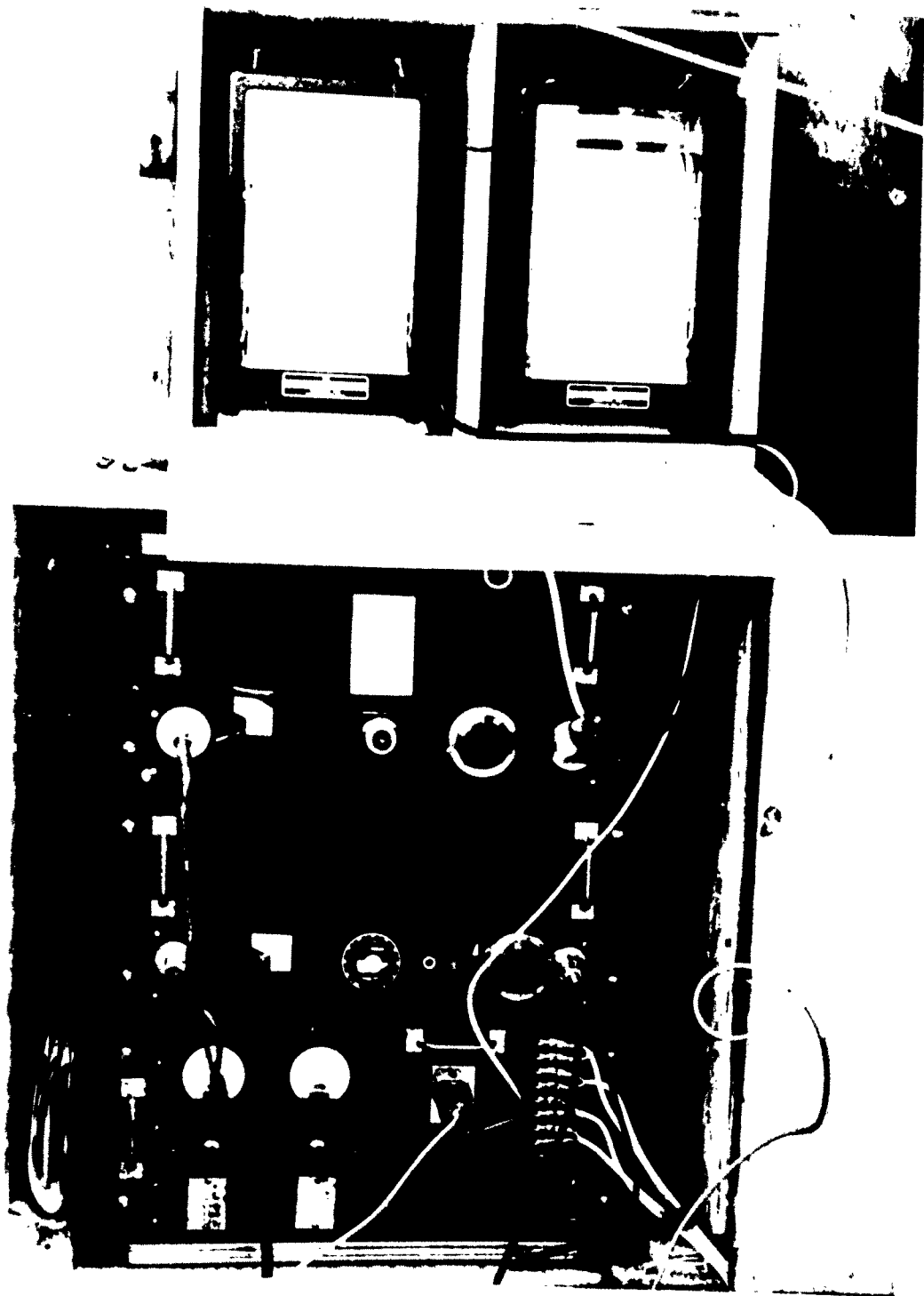


FIG.4. AMPLIFYING AND RECORDING EQUIPMENT  
AS MOUNTED IN BOAT.